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THE IMPORTANCE OF BASIC RESEARCH FOR INVENTIONS AND INNOVATIONS IN WIND INDUSTRY. SOME EXPERIENCES FROM DENMARK AND CHINA 1973 – 2011

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Abstract

Wind generated production of electricity by use of wind turbines began by inventions made at nearly the same time but independently by three natural science academic educated people as the Scotch professor in electrical technology James Blyth in 1887, the American mining engineer Charles F Brush during winter 1887-88 and the Danish physicist and meteorologist Poul la Cour in 1891.
The Blyth and Brush turbines were constructed from existing technologies with the purpose to satisfy the inventors' personal needs of electricity. The la Cour turbine was intended to deliver electricity to rural districts in Denmark. With the traditional Dutch wind mills at that time it was possible to harvest 7 percent of the energy in the wind. For la Cour it was clear from beginning that this yield percentage should be much higher if wind electricity should be relevant in practice. The solution came with help from two Danish engineers H C Vogt and Johan Irminger who made basic research in aerodynamics a little bit of time before la Cour started up (Guy Larose and Niels Franck: Early wind engineering experiments in Denmark, in Journal of Wind Engineering and Industrial Aerodynamics, 72 (1997), pp. 493-499).

Danish experiences

When we take a closer look at the Danish experiences we need to stress something more specifically.
First of all basic research competence in aerodynamics survived after Vogt, Irminger and la Cour at the Technical University of Denmark (Ibid).
Second the Gedser Wind Test Turbine was a test turbine in Denmark after Second World War designed, established and supervised by Johannes Juul. It included all la Cour's and later contributions and worked without serious problems 1957-67.
Third it is important that Danish wind energy after the first energy crisis 1973-74 made a jump from small handicraft into serial industrial production with production in Denmark and instalment in California 1981- 87 of about 7, 300 turbines.
Fourth the nuclear test station Risø became a very strong wind energy research institution. Primary an applied research institution it had also strong links to the industry and users because of test facilities. Basic research and some applied research are today taken place in Technical University of Denmark where Risø today is a part and Aalborg University.
Today the industry consists of two big companies making wind turbines, Vestas Wind Energy and Siemens Wind, and one big company producing blades for turbines, LM Wind. However there are many small or medium sized companies delivering special goods or services connected to IT services, instalment of turbines, wind park services and many other things.

Chinese experiences

Modern wind energy came to China from mid-1980s. It was turbines from Denmark, Germany and Spain. The very first turbines were three Vestas 55 kW turbines imported from Denmark. The Chinese conducted very little experimental works in the beginning. However they learned from the foreign companies. During the period 1995-2003 Central government institutions

made guidelines for new energy and renewable energy. There were established some demand creating measures. Joint ventures between foreign and Chinese companies and incentives for competition resulted in localization of large scale wind turbines.
Since 2003, especially since the implementation of the New Energy Law from January 1, 2006 the Chinese Wind sector has been developing very fast. Wind projects less than 50 MW should not more get approval from central authorities which stimulated local wind parks. However 70 percentages of the content in wind turbines should be produced in China. Companies as Goldwind, Sinovel and East Auto Group developed wind turbines with more than 1 MW effect. Pitch controlled technology was introduced and in 2005 Goldwind developed in cooperation with Vensys a 1.2 MW direct drive turbine.
Today there are 20+ companies which can produce turbines in the interval of effect from 700 kW to 1.5 MW. However China still do not have their own platform for developing manufacturing technology. First of all because of lack of basic research. Most of manufacturing technology is still basically imported technology. Key modules and components as gearboxes, blades and electricity controlling systems are still coming from Germany, Denmark, Spain, Sweden and U.S.A. In the few cases with Chinese technology the operation experiences are very few.
There can be identified three types of R&D modes in China today. First type is the Goldwind type which is doing their own applied research and development work in cooperation with government research institutes. The second type is domestic research institutes. The wind energy technology institute of Shenyang University of Technology has made wind electricity research since 1983. Nearly 20 companies have adopted technologies from that institute. Finally the third type is the Sinovel model. Here we have purchase of foreign design technologies, jointly R&D and local manufacturing.

Hypothesis and methods

From authors as Richard R Nelson and Joel Mokyr and standard literature in economics of science, inventions and innovations we have made the following hypothesis:

Basic research will give controllable and testable results of general character which can reduce uncertainty in our knowledge of the field in which we are doing research

We are using published literature and information from interviews as sources.

Key Words:

Basic research, aerodynamics, material sciences, software, wind turbines, Denmark, China.

1 INTRODUCTION

Wind turbines for production of electricity have from their very beginning, with the contributions from the Scotch professor electrical technology James Blyth in 1887, the American mining engineer Charles F Brush during winter 1887-88 and finally the Danish physicist and meteorologist Poul la Cour in 1891, been characterized with two main traits: 1) they are *complex*, and 2) they are *science based* in their technology.

In all literature on wind energy and wind turbines there is agreement in respect of the question on the complexity of wind turbines. There are many components with many connections inside a module. The modules on their side have many connections to other modules. The main argument for this complexity is first of all because of the erratic character of wind. That has been evident for all wind turbine constructors, engineers or self made practical men. What has sometimes been discussed is about which qualifications are the most important in organizing production and further development of wind turbines. It is interesting to notice that all three pioneers were academic educated and intellectual well trained in some topics used to construct their turbines. But they were also practical people. In fact Poul la Cour was called *Denmark's Edison* because of his many inventions also made before he shifted his focus into the wind field.

The question about the science based character of the knowledge needed to build and develop new wind turbine technology is much more controversial in the literature especially the academic part of that. Arguments for a strong science foundation of wind turbine technologies are first of all about the aerodynamic forces of the wind and the turbines located in specific places with wind influenced from the locations. The question about the architecture or the concept of the turbine which is about the horizontal axis or the vertical axis concept is also connected to the question of aerodynamics but is also influenced by economic considerations. Other arguments are focused on the scientific foundation of the many different technologies used in a wind turbine – for example materials used in blades and other parts of the turbine, the software used in controlling the speed of the blades of the turbine in the dynamics of wind and how to locate the turbines vis-à-vis each other in a wind park to minimize the shadow effects and in this way diminishing the energy which can be utilized to move the axis connected to the generator. Arguments against a strong science foundation of wind turbine technologies are first of all based on the observation that sometimes development of new types of wind turbines seems to have been made by practical men without a deep understanding of relevant science. The Danish renaissance in wind turbines during 1973 – 85 has been a reference history for these arguments[1].

In *section 2* concepts like public goods and *global public goods* are presented as tools to understand the character of scientific knowledge of importance for technology, not only basic scientific knowledge but also applied scientific knowledge used in development of new types of turbines and more concrete product development.

In *section 3* the importance of basic research as an activity and the importance of the results from basic research is presented and discussed. A basic *hypothesis* is formulated postulating that basic research of quality in methodological respect gives controllable and testable results which can reduce uncertainty in later applied research and development.

[1] Garud, Raghu, Peter Karnøe: "Bricolage versus breakthrough: Distributed and embedded agency in technology entrepreneurship" in Research Policy, Vol. 32, Is. 2, 2003, pp. 207 – 300. Jørgensen, U., Karnøe, P.: "The Danish wind turbine story: technical solutions to political visions?" in Rip, A., Mica,T.J., Schot, J. (Editors): Managing Technology in Society: The Approach of Constructive Technology Assessment, Pinter Publishers, London, 1995. A recent critique of these position is given in Chris Hendry, Paul Harborne: "Changing the view of wind power development: More than "bricolage"" in Research Policy, Vol. 40, Is. 5, 2011, pp. 778 – 789.

In *section 4* the following question will be asked – which arguments first of all economic arguments can be used to defend use of national public funds for production of global accessible scientific knowledge which we expect from economic theory can be understood and applied for free by companies and persons all over the world without paying for these scientific activities and creation of the results?

Section 5 presents important relevant information about Danish development in wind turbine technology and look at connections to basic science focused on the period 1973 – 2011.

In *section 6* the Chinese development which in fact first started up from mid-1980s will be presented.

In *section 7* analysis of empirical material will be done with purpose to test the hypothesis mentioned above in section 3.

In *section 8* conclusions will be given.

2 BASIC RESEARCH RESULTS AS GLOBAL PUBLIC GOODS AND THEIR PRODUCTION

In economic theory an important distinction has been made between *private goods* and *public goods*. The idea is to look at goods, including services, from two different angles. The first is from the angle of *rivalry – non-rivalry*. A specimen of a rivalry good can't be consumed or used by more than one consumer or user. A certain specimen of bread or a cup of coffee are two different examples of rivalry goods. Non-rivalry goods are characterized as goods which can be consumed or used by many consumers or users without diminishing the utility for other consumers or users. If all people are protected by defense or everybody can write or read there are no utility losses for other people. The second angle is *exclusivity – non-exclusivity*. A good is exclusive if the owner of the good can exclude or prohibit other persons or companies from getting access to consume or use the good. The exclusion can be made by the police or from social norms in most people saying that you shall not steal from the baker or the coffee shop owner.

A good can be non-exclusive because of its s physical qualities. It will be very difficult to prohibit a person from looking at traffic lights[2].

In real life there are pure private goods characterized as rival and exclusive and pure public goods characterized as non-rival and non-exclusive. However there are also impure cases in which goods are mostly perceived as *impure private goods* as for example newspapers given for free. With this type of newspaper thousands of copies where the paper copy, not the content, individually is a rival good, are given for free which mean that it is now a non-exclusive good. Another example is an *impure public good* where access to knowledge which is non-rival is protected for the owner by help of a password. It can be the case of TV-satellite signals or the source code in closed software programs.

Public goods at *national* level have been known for centuries – defense services, schools delivering education at different levels and scientific research results from universities. What is a new phenomenon at least at the level known today is that some public goods have been *global* in their

[2] Joseph E. Stiglitz: "Knowledge as a Global Public Good" in Inge Kaul, Isabelle Grunberg, Marc. A. Stern (Editors): Global Public Goods. International Cooperation in 21st Century. Published for The United Nations Development Programme (UNDP), pp. 308-325, Oxford University Press, New York and Oxford, 1999.

consumption or use. Examples of such global goods are basic scientific results published in English which in fact has been the global research language and distributed in journals or papers accessible from the internet or cultural goods from fine art to mass entertainment which are spread by TV or the internet. Another example of a global public good is a rain forest with its importance for global climate.

We shall now ask the simple question – *who will spend their own resources for production of public goods?* If we start looking at the situation on national level the answer traditionally given has been that individual persons or companies will not do that because most of the potential utility which can be harvested from the results will go to society and only a small part will be used by the single person or a company considering investment in production of the good. However the national state can be thought as a representative for national business and/or the common good in society. Therefore government will collect taxes and give common and free access to the results if they are considered to be sufficiently valuable in economic or cultural respect.

In section 4 below we shall come back to the question about funding of basic research activities.

3 BASIC RESEARCH AS ACTIVITY AND AS RESULT

Usually *basic research* in natural science will be considered as consisting in endeavoring to identify *general* traits in matter and energy, living or dead, but also mapping of *structural* characteristics as the Periodical System, DNA mapping or the geographical traits of the Earth[3]. Basic research is first of all about general regularities or laws, the Natural Laws. A basic research question can for example ask about the influence from the angles of blades toward the wind of different speeds in respect of energy harvested in percentages of the energy in the wind.

Applied research is more focused at specific traits and will usually be interested in which results we can expect if we make certain interferences in a machine of a well defined type, e.g. how the angle of a blade towards the wind of a certain speed will influence the energy harvested from the wind by that turbine. Applied research is concerned about making prescribing knowledge or receipts telling what to do if you want certain, typically an optimal result.

The importance of basic research can be understood both as a *process* and from the achieved *results*. The last is usually well understood – you know from thermodynamics that energy will always be conserved but can change forms, it can't be destroyed. That means you can't make a perpetuum mobile, a machine which can work eternally without getting energy from outside. What is usually less well understood is the importance of working in a scientific way even you will not produce true or workable results. Tycho Brahe and Johannes Kepler were working with astrology and their astronomy was maybe a side effect to that. Both Isaac Newton and Tycho Brahe were alchemists trying to transform cheap materials as lead into gold. Even they didn't achieve their wanted results they worked methodological in a scientific way and natural they had to stop because of empirical falsification of their belief. And by working in that way they sometimes discovered regularities which learned them something about universe or matters which were important and a part of modern science.

[3] The distinction between basic research and applied research has been inspired from Joel Mokyr who has made a distinction between propositional knowledge ("what" knowledge) and prescriptive knowledge ("how" knowledge) but is not identical. See Joel Mokyr: The Gifts of Athena. Historical Origins of the Knowledge Economy. Princeton University Press, Princeton, 2002. Another important work from Mokyr is: Joel Mokyr: "The Intellectual Origin of Modern Economic Growth" in The Journal of Economic History, Vol. 65, No. 2 (June 2005), pp. 285-351.

Gary P Pisano has in an article with a very good title "*Learning-before-doing* in the development of new process technology" (the cursive has been made by us, JLP & KXX) demonstrated that in chemical synthesis it is possible to design laboratory experiments which can tell much about future production experiences. It is possible because of two hundred years accumulated theoretical and empirical knowledge. In modern biotechnology there is still not such a body of useful knowledge. Therefore work takes place as a case-by-case-research and development process. It is evident that in the theoretical and empirical well founded chemical synthesis progress will be faster and cheaper than the case will be if you have to work with a case-by-case approach where you can't use many accumulated results from other cases because of weak basic theoretical knowledge[4]. It shall be stressed that today more than 15 years after the article was written the situation can have changed in biotechnology.

Our hypothesis in this paper will be the following: *basic research will give controllable and testable results of general character which can reduce uncertainty in our knowledge of the field in which we are doing research.*

It is the *general* character of the results from basic research which is important. We get results *about a class of phenomenon not only one specific phenomenon.* The Periodic System, DNA mapping and mapping the geography of Earth are naturally of another character, we have in lack of a better word called that type of basic research *structural basic research.*

This *reduction in uncertainty is important in later applied research and development*.

4 WHY NATIONAL GOVERNMENTS ARE PAYING FOR PRODUCTION OF GLOBAL BASIC RESEARCH

If it is true that basic research results today are global public goods which can be used for free by competent people all over the world without having paid for production of them it can only wonder why?

In fact there are also politicians and some business people wondering about that. They have tried to *expand patenting outside the technical invention field* which is the classical core for patenting. In this way a state supported monopoly system will be created outside invention activities. But *if it will be allowed to patent discoveries we shall observe very unproductive and anti-scientific processes in science*. A consequence will be the possibility to patent natural laws which would stop scientific and later on technological progress. In IT programming and genetics clashes between private profits and social needs for science has already been observed in U.S.

In literature different answers are given to the question asked above:

1. The closer in geographical and cultural sense the country's companies are to the universities in the country with their basic research the easier and faster it will be for the companies to establish personal contacts and get some information about research topics and maybe hire people to work in a supposed commercial relevant way with their research activities.
2. Another answer can be that high profiled basic researchers can establish contacts to important research groups in other countries. In Denmark we have one important case when Professor

[4] Gary P Pisano: "Learning-before-doing in the development of new process technology" in Research Policy, Vol. 25, Is. 7, October 1996, pp. 1097 – 1119.

August Krogh, who got the Nobel Prize in medicine in 1920, in 1922, was invited to deliver lectures about his research at Yale University. He and his accompanying wife suffering from diabetes heard about a method to inject insulin from animals into human beings developed and tested in 1921. They established contact to the group of researchers in Toronto in Canada which had made the research behind the treatment, and which later got the Nobel Prize in medicine. The result was a license to start up production of insulin in Denmark based on extraction of insulin from animals. Novo Nordisk A/S which is the still existing company established in that way is today the biggest insulin producer globally.

3. Another case from Denmark is the establishment of the private funded Carlsberg Laboratory in the end of 19th Century with the purpose to perform basic research in chemistry and physiology but not to help the production of beer. The Foundation with responsibility for the Laboratory became owner of the Carlsberg Brewery when the brewer died. The intention from the brewer was that the private business should pay back to basic science what basic science had done for business. However government paid indirectly and to some degree for the Carlsberg Foundation and Carlsberg Laboratory construction.
4. Government can have a specific state financial interest in such spin offs from basic research because of production, income, export and/or import substitution and naturally employment which all will be good for public finances,

Even most of basic research is still directly paid from national public funding or indirectly because of tax subsidizing of private companies' basic research activities, there are also some international organized basic research in EU, European Science Foundation and UN paid from national governments.

5 DANISH WIND DEVELOPMENTS 1973 – 2011

5.1 The Gedser Turbine 1957 – 67 – A Synthesis of nearly 70 Years Research, Development and Practice

When First Oil Crisis 1973 – 74 with its quadruplicating of oil prices hit the world the effect was naturally a global process. However in Denmark there were three specific traits. First of all Denmark was without significant resources of fossil energy. Second there was a very strong resistance from most of population against nuclear power. Third Denmark had a history with some theoretical based construction and running of wind turbines for production of electricity[5].

The so called Gedser Turbine with a rated effect of 200 kW constructed and later on supervised by Johannes Juul 1957 - 67 represented a synthesis of all the best results from Poul la Cour in 1891 through the Agricco turbine in 1918 and the F L Smidth turbines during the German Occupation of Denmark 1940-45. Two important jumps in efficiency of utilizing energy in wind took place before the Gedser turbine was constructed. The first was that la Cour in his cooperation with Vogt and Irminger, two Danish engineers, after they had made important contributions to basic aerodynamic theory was able to let mechanical energy be harvested from the kinetic energy in wind go up from 7

[5] Benny Christensen (Editor): Wind Power – the Danish Way. From Poul la Cour to Modern Wind Turbines. The Poul la Cour Foundation, Askov, 2009. See also Jørgen Lindgaard Pedersen: "Science, Engineering and People with a Mission: Danish Wind Energy in Context 1891 – 2010", paper presented at The International Schumpeter Society Conference, Aalborg, Denmark, June 21 – 24, 2010.

% in the pre-la Cour Dutch Windmill into 21 % in his final version, the so called “klapsejler” in Danish consisting of a series of shutters which can change air flows through the blades, based on the new aerodynamic theory (that percentage should be about 30 from about 10 if it shall be compared with the way measurements are done today namely by the area swept by the blades). The second took place in Vinding and Larsen’s, two other Danish engineers, Agricco turbine from 1918 with 43 % compared with 59.3 % which is the theoretical maximum (the Betz Limit) and 48 % what was the practical maximum in 1980s. The jump in efficiency in transforming kinetic energy into mechanical energy and finally electrical energy was 50 % from la Cour to Vinding and Larsen. The main cause for that was learning from aerodynamics in theoretical and practical respect from airplanes and design of propellers[6].

The Gedser Turbine was erected in Gedser in a windy area at the coast towards the Baltic Sea in 1957. It was paid partly from some funds left from the Marshall Funds and some Danish public funds. In fact there were two test turbines in 1950 and 1952 before the Gedser Turbine also constructed by Johannes Juul. They were smaller, 15 and 65 kW compared with the 200 kW effect in the Gedser Turbine and they had only two blades compared with the three blade version in the Gedser turbine. The blades were stall regulated and there were brakes at the end of each blade and a mechanical brake to regulate the power output. A yaw mechanism with a motor kept the rotor upwind during operation[7].

The turbine worked well without problems until 1967 when a minor fault in the gearbox was used as argument for stopping its operations. However the real background was that the cost per produced Gcal from the turbine was DKK 17 – 19 compared with DKK 8 – 9 from coal produced electricity[8]. It shall be stressed that environmental effects were not taken into account as externalities in the calculations at that time. It was first done after the climate debate started up after the two oil crises in 1970s.The dominant part of Danish industry and electricity production and distribution was thinking in nuclear power as the electricity technology for the future. However in 1978-79 the turbine was repaired with funding from US government body Energy Research and Development Administration (ERDA). Many measurements and security tests from the first period were followed up[9].

The importance of the Gedser Turbine was first that it represented the optimal design incorporating la Cour’s and the Agricco Turbine’s aerodynamic progress based on the new aerodynamic basic research. Second it was constructed taking into account a maximum of security and stability in running operation which meant very few accidents and stoppages during which no electricity could be produced.

5.2 The Tvind Turbine and the Riisager Turbines 1975 - 78 – Giant Turbine plus Modularity and Serial Production

The First Energy Crisis started up in October 1973 and ended in March 1974 and as mentioned above the result was a quadruplicating of oil prices. What happened immediately was what has been

[6] Ibid and Jytte Thorndahl: Gedsermøllen – den første moderne vindmølle [title translated into English: The Gedser Turbine – the first modern wind turbine], Elmuseet, Bjerringbro, 2005.
[7] Jytte Thorndahl: ”Johannes Juul and the Birth of modern Wind Turbines” in Benny Christensen op.cit. pp. 40 – 45.
[8] Fakta om vindenergi, M5 www.dkvind.dk/fakta/pdf/M5.pdf
[9] Jytte Thorndahl, op. cit. in Benny Christensen (Editor), op.cit.

called a “popular spirit of engineering”[10]. Many different people and companies developed ideas about how to produce alternative energy, not only from wind but also from biogas and solar energy. In wind there were companies and persons with a history back in wind e.g. F L Smidth with its wind turbines during Second World War. Other companies had a background in equipment delivered to agriculture e.g. Vestas (wagons) and Danregn (irrigation equipment) later on Bonus and today Siemens Wind Power. Finally there were also several blacksmiths and craftsmen from many other industries who started up producing wind turbines. They were not scientific trained but they knew whom to ask about the simple wind science and practice from la Cour via the Agricco Turbine and synthesized in the Gedser Turbine described above.

One astonishing trait if you look at pictures and read the literature from these very first years is the many different designs. Remarkable is the many designs based on the Vertical Axis concept with the Darrieus concept as the dominant version[11]. In fact F L Smidth which left the wind turbine field just before it really (re-) started up supported the Darrieus concept in 1975. And the first turbine Vestas considered production of and in fact had a specimen of installed at the plant area was a Darrieus turbine. In the official Vestas history writings there are typically only a short hint to that part of history saying that it was abolished because of technical problems. Risø Teststation had also a Darrieus turbine installed at that time[12].

The restart of Danish Wind turbine production and installment was first of all characterized by two important manifestations of new times. First of all during the three year period May 1975 – March 1978 the youth School Community Tvind located in Western part of Jutland constructed and erected a very big turbine, in fact the biggest turbine at that time, with an effect of 2 MW. It had revolving blades instead of the traditional fixed blades. The blades were also innovative in respect of aerodynamics and structural characteristics. The generator was a synchronous instead of the asynchronous type. A very important characteristic of the turbine was that it was conceptualized as a modular construction where most of modules were bought from other types of equipment in a tank ship (main shaft to rotor), mining (gearbox) and electrical equipment (generator)[13]. That concept with *off-the-shelf modules* came from the leader of the Tvind School Concept Amdi Petersen. The technical expertise came from outside. Professor Ulrich Hütter from the Technical University in Stuttgart helped with construction of the blades made from fiber glass. He had been leader of Hitlers wind project during Second World War. Professor Ulrich Krabbe from Technical University of Denmark (at that time Technical High School of Denmark) helped with construction of a frequency converter control system. Most of the manual work including building of the fiber glass blades was done by young people without training but with a strong commitment against nuclear power and for alternative or renewable energy.

A problem with vibration in the turbine had resulted in the fact that the turbine couldn’t work with an effect of more than 0.9 MW. However that problem has not hindered that the turbine has worked without many problems and after a renewal some years ago it still works here in 2012.

The second important manifestation was introduction of *serial production* in manufacturing of wind turbines. Serial production means that several numbers of an identical wind turbine are produced. In practice serial production presupposes uses of identical modules and components. The serial production principle was introduced by Christian Riisager in 1976. He was also a self made man

[10] Preben Maegaard: ”Nogle af ideerne, der forsvandt undervejs” [title translated into English: Some of the ideas which escaped en route] in Kapitler af vindkraftens historie i Danmark, 3. årgang, 2007, pp. 23 – 29 (in Danish).
[11] Science, New Series, Vol._ 189, No._ 4199 (Jul_ 25, 1975), pp_ 237-312.
[12] Preben Maegaard, ibid.
[13] Ibid

who had worked as a carpenter most of his life. The principle became decisive for Danish wind turbine producers few years later when they produced several thousand turbines in five – six years to be installed in California.

The two important manifestations mentioned above – off-the-shelf modules used in construction of the turbine and serial production of wind turbines – were important for the industrialization of the coming mass production of wind turbines which became standard from beginning of 1980s.

However it can't be said that the two tendencies were results of basic research, at least not research in natural science. They were maybe inspired from what could be seen in other industries during the American inspired modernization after Second World War which was partly financed from the Marshall Plan funds given from U.S. to Denmark and other European countries. There were naturally also results from research and practical experiences from organizational and technical thinking, also with some scientific qualities.

5.3 The Export Boom of Wind Turbines from Denmark to California 1982 – 86 – Transformation into localized International Business

From beginning of 1980s Californian politicians decided that something should be done with the air pollution in the state. A tax allowance scheme made it very profitable for Californian citizens to invest in wind turbines. In 1982 four of the biggest wind turbine producers in Denmark decided to start up export of turbines to California and erect them in wind parks there. A little bit later three other companies joined the pioneers. During the period from beginning of 1982 until end of 1986 7,277 wind turbines with a total effect of 550 MW were produced and exported from Denmark to California. The export boom stopped with the end of 1986 because the tax allowance stopped at that time. The export figures to California were 7 times the figures for turbines installed in Denmark in the same period[14].

Why could Danish companies take part in the California Wind Rush? First of all we think because Denmark had a well proved design and concept from the Gedser Turbine. The U.S. buyers and the Californian State claimed very high reliability of the turbines in operation and documentation for that. The documented operation of the Gedser Turbine became now extremely important. Because the Californian scheme should only run for a short period (from about 1980 until end of 1986) it was very clear that time was not accessible for developing new technologies and concepts. So there was no basic research with immediately relevance during these years. Naturally there were some applied research and development works because of the big series produced for California and because installment took place many thousand kilometers away from plants in Denmark. However the design and concept from the Gedser Turbine became now the Danish Concept and not only in Denmark but globally. The wind test station located at the Risø area together with the growing mostly applied research in wind and wind turbines in the Nuclear Power Research Station Risø resulted in that the center of wind research in Denmark became located here, 40 km from Copenhagen.

[14] Birger T Madsen: "Public Initiatives and Industrial Development after 1979" in Benny Christensen (Editor), op.cit.

5.4 The permanent Growth in Turbine – Size, Clustering in Wind – Parks and Off – Shore Activities 1990 – 2011 - Transformation into Global Business

When the Californian market disappeared at the end of 1986, the date of which was known in beforehand also in the Danish companies, 85% of the market for the Danish wind turbine companies disappeared. Fortunately for the companies now there became established programs for wind energy in European countries as Germany and Spain which could be relevant markets for Danish companies with experiences from California. Still the disappearance of the enormous Californian market was so dramatic an event that all the seven companies with exception of Bonus (today Siemens Wind Power) went bankrupt. After some financial rearrangements they reappeared. Some of them became stock companies. That was the case with Vestas which was changed from a family company into a stock company Vestas Wind Systems A/S.

During the last twenty year after 1990 the wind turbines have first of all grown continuously in *size* measured in rated effect from about 150 kW to 5 – 6 MW for the biggest and 2.5 – 3 MW in average of on shore turbines in 2011. Second the turbines have nearly all been installed in *wind parks.* There has been made economic research trying to estimate the importance on productivity growth from this growth in turbine size. Sondes Kahouli-Brahmi has in an article from 2009 estimated the *scaling up* effects and *learning* effects (in practice all other effects than scaling up effects). She has used figures from EWEA (European Wind Energy Association) and estimates that 60 % of the productivity growth in production of electricity comes from scaling up the turbines. The other 40 % comes from learning effects (learning by doing, learning by using, learning by searching and learning by interacting)[15]. This figure shall be compared with growth rates in yearly total factor productivity during most of the period on 1.5 – 2.0[16]. It shall especially be remembered that price movements affect the productivity movements measured in that way. *Total factor productivity (TFP)* is a measure differing from *labor productivity* in the way that usually capital goods substitute labor and total factor productivity will be less than labor productivity. What happens with *changes* in TFP and labor productivity is another thing. The percentage of kinetic energy transformed into mechanical energy seems to be around 50 % with the Betz Limit as the theoretical maximum of 59.3 %[17].

It is remarkable that in a period during which public and private research and development in wind energy experienced a high rate of growth the percentage of kinetic energy transformed into mechanical energy went only up from 48 % in 1980 to 50 % in the 00’s compared with the very high growth rates in this percentage from about 10 % before la Cour to 30 % (not 21 % as measured by la Cour himself) to 43 % in 1918 as mentioned above[18]. Naturally the social relevant measure is the economic cost of energy (CoE) which is reciprocal of the total factor productivity. And its growth rate has been estimated to be about 1.5 – 2.0 % per year during most of the period. Explanation of that can be that materials have been cheaper, with exception of the years from about 2005 until about 2010, industrialization of production methods has lowered the unit manufacturing and finally transport and installment of turbines have been rationalized so the cost per installed MW and produced kWh has been lowered. And probably lots of R&D resources have been allocated to

[15] Sondes Kahouli-Brahmi:”Testing for the presence of some features of increasing returns to adoption factors in energy system dynamics: An analysis of the learning curve approach” in Ecological Economics, Vol. 68, Is. 4, 2009, pp. 1195 – 1212.

[16] Søren Krohn, Poul-Erik Morthorst and Shimon Awerbuch: The Economics of Wind Energy. A Report of the European Wind Energy Association, 2009, pp. 1 – 156.

[17] Sandra Eriksson, Hans Bernhoff, Mats Leijon:”Evaluation of different turbine concepts for wind power” in Renewable and Sustainable Energy Reviews 12 (2008), pp. 1419 – 1434, p. 1426.

[18] See this paper p. 8.

understanding and solving problems of these types instead of the aerodynamic problems connected to extraction of mechanical energy from the kinetic energy in wind.

One further development shall only be mentioned because it probably will be important in the future in some part of the world. We think on the off – shore wind parks. They represent not only moving wind turbines from land into the sea. Because of the character of wind off – shore and problems with foundations when the turbines move to seas with more than 30 – 40 meter depth there are really important challenges also for science and engineering. DTU Risø is coordinating a EU funded feasibility project with a vertical Darrieus type big turbine to be installed at the open ocean with depths of 1 – 2 km.

6 CHINESE WIND DEVELOPMENTS 1970s – 2011

In this section we trace the historical evolution of technology capabilities of Chinese wind sector, and map the R&D chain by wind companies, universities, and research institutes in China. It could be traced to 1000 years ago for the usage of wind energy in China. It was nearly the earliest wind-wheels, which has been used until so far for irrigating. However, wind electricity in China has been developing later only since 1980s. It reflects the interdependence process of basic research, applied research and experimental development. In basic, during the process of Chinese wind energy sector development, basic research, and applied research and experimental development has been conducted parallel. Basic research has been lagging behind from applied research and experimental development due to the requirements of different development stages. It had also caused problems of wind sector development.

From 1985 to 1995, China took usage of the governmental loans from Denmark, Germany and Spain, conducted some little experimental projects. European countries brought their wind turbines to Chinese market and made the experimental operation, which accumulated many experiences. Chinese domestic firms initially learned from foreign firms. The very initial technology sources in Chinese wind sector came from 3 Vestas 55 kW wind turbines imported from Denmark. However there were also some minor Chinese activities during these early years. In 1988 the Hang Zhou Machine Design and Research Institute cooperated with seven other factories and institutes and developed successful China’s first 200 kW wind turbine[19]. There were during this phase from late 1970s to 1995 first of all government interest in establishing basic knowledge about wind and wind power and getting understanding of the vast gap between the West and China in that field[20].

From 1995 to 2003, Chinese government issued many different encouragement policies. In early 1995, National Development and Reform committee, Committee of Economy and Trade, and Ministry of Science and Technology jointly published Guideline of China New Energy and Renewable Energy Development 1996-2010, implemented Chengfeng Plan and Double Plus Engineering project. Through the mode of Government creating demands, Joint ventures producing and market orderly competition, the localization process of large scale wind turbines had been speeded up.

Since 2003, especially after the implementation of New Energy Law on January 1st, 2006, Chinese wind sector has been developing very rapidly. National committee of Development and Reform

[19] Peng Ru, Qiang Zhi, Fang Zhang, Xiaotian Zhong, Jianqiang Li, Jun Su: “Behind the development of technology: The transition of innovation modes in China´s wind turbine manufacturing industry” in Energy Policy 43 (2012), pp. 58 – 69.
[20] Op.cit., pp. 63 - 64

loosed the approval right of the wind electricity projects below 50 MW through concession operation, which requested the localization rate of domestic wind electricity projects not lower than 70%. Goldwind, Sinovel and East Auto Group developed MW type wind turbines, and gradually adopted the pitch controlled technology. In May 2005, Goldwind collaborated with Vensys, and successfully developed 1.2MW direct drive wind turbines, and did the trial experimental operation in Xinjiang Dabancheng.

So far, there are more than 20 manufacturers with the production capacities of 600 kW, 750 kW, 1 MW, 1.2 MW and 1.5 MW. However, China still doesn't have established the R&D platform system for promoting manufacturing technology, especially because of the lack of basic research. Most of the Chinese wind turbine manufacturing technology is basically imported technology, and a few domestic R&D wind turbines type have still had very limited operation experiences. Key technologies and component of wind sector of blades, gearbox, barriers, generator and electricity controlling system mainly rely on import from Germany, Denmark, Sweden, Spain and USA.

Technology capabilities have been accumulated during the upgrading process of Chinese wind sector. Chinese government has played an important role in strengthening R&D of wind turbines manufacturing. Since 1980, during every five year plan stage, the Ministry of Science and Technology supported wind energy relevant technology fields R&D. In the Seventh and Eighth Five Year plan stage, 150 kW ~ 300 kW were funded. In the Ninth Five Year Plan stage, 600 kW wind turbines R&D were funded. In the Tenth Five Year Plan stage, 750 kW wind turbines R&D were funded. And during the same period time, changing speed generator technology of the MW type wind turbines was funded.

It could be summarized with three types of R&D modes in Chinese wind sector. The *first type* is Goldwind type. Goldwind was set up in 1998 and is one of the earliest companies to conduct wind electricity R&D. During its development process, it has been supported by the national S&T plan of Nineth Five Year Plan, Tenth Five Year plan and Eleventh Five Year plan. In 2004, it set up the National Wind Electricity Engineering Technology Research Center approved by the Ministry of Science and Technology. The main products of Goldwind are 750 kW, 800 kW, and 1.5 MW direct drive wind turbines, which are sold to 23 wind plants in China. It developed also 2MW and continues to conduct the R&D of 2.5 MW and 3 MW. The *second type* is domestic research institutes. Wind energy technology institute of Shenyang University of Technology has been starting wind electricity research since 1983. It has transferred many MW type technologies to the whole sector in China. Nearly 20 companies like East Auto Group, Lanzhou Motor, adopted technologies developed by this university. The *third* is purchase of foreign design technologies and jointly R&D and local manufacturing. For instance Sinovel got the Fuhrlander 1.5 MW MD70MD77 overall design technology through paying 4 million Euros for the relevant licenses.

In all, Chinese wind sectoral R&D system is the open system, in which foreign actors including play important role as well. In this paper, we try to say something about the competition and collaboration space of R&D system by the basic research, applied research and experimental development by Danish and Chinese companies, research institutes.

7 ANALYSES

The main *hypothesis* said that *basic research will give controllable and testable results of general character which can reduce uncertainty in our knowledge of the field in which we are doing research.*

It seems to be evident that (re-)establishing the Anti – Newton research paradigm in aerodynamics from beginning of Poul la Cour's work from 1891 and continuing the following years had decisive influence on the growth in the capacity to transform kinetic energy in the wind into mechanical energy to make electrical energy from 7 % to 21 % or measured by swept area is from about 10 % to 30 %.

It is also evident that the jump in this percentage from 30 % to 43 % in the Agricco turbine also came from aerodynamic theoretical work connected to the more or less parallel work in airplane science – a development la Cour apparently didn't knew about or at least didn't took into account.

It is really striking that the percentages of kinetic energy transformed into mechanical energy has only grown from 43 % in 1918 to 50 % in 2011 more than 90 years later. We have not analyzed this remarkable fact. There can be speculated in different answers. One possibility can be that rising marginal costs in R&D in respect of this type of work can be found. The idea is that the low hanging fruits will be picked first. Another answer can be that in *economic* sense it has expected that profit will be higher by focusing at other productivity influencing part of the wind energy system e.g. size of wind turbines or clustering the turbines in wind parks located where the wind is of high quality, stable and strong.

What seems to be important for development of wind energy technology today is the scaling up of the turbines and learning from many different sources. During the pioneering years, which in Denmark were 1891 – 1918, it was easy to identify where the relevant research was done, namely in aerodynamic basic and applied research. Today a good part of the technological development in wind turbines and wind energy in general comes from scientific and technological development in new materials, laser technology and software. However these scientific and technological fields are what have been called General Purpose Technologies and what we can call General Purpose Sciences. That means that important basic research will not be inspired only from need to understand challenges in wind and wind power. An example which can be mentioned is use of bamboo fibers in blades which comes from research in light and biodegradable materials. Here we have a Chinese contribution to science and technology over a general field which can be used also in wind turbines. What has been important as a consequence of this R&D is that down time has been reduced because of higher quality of materials, components and modules and from more optimal repair and maintenance programs. That is naturally very important in economic terms.

8 CONCLUSIONS

1) The high quality of the basic research in aerodynamics from the work done by Johan Irminger, H. C. Vogt and Poul la Cour and later on by Poul Vinding and Johannes Larsen during the period 1891- 1918 changed a relatively intuitive common sense and half – right scientific Newtonian understanding of the art of harvesting energy from the wind into a much more precisely scientific conceptualized and tested theory. The uncertainty in designing effective wind turbines became much less and the same with the economics of the outcome of electricity from the turbines.
2) With use of the concepts public goods and global public goods we have got some concepts to understand the specificities of basic research as results and activities. There have been given some arguments for rational national governmental support to basic research even when the results are open for everybody all over the world.

3) The main arguments are in fact based on expectations that important hints to what goes on in basic science can be the future in technology. These hints will easier diffuse to national companies or individuals, researchers or other, who will consider establishing their own new companies based on the basic research before foreign companies can do that.
4) Each stage in development has been born from problems in the earlier stage but naturally not in a simple way and not in a very mechanical way. However problems to be solved are decisive and not only the possibility to think out of the box.

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